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10.1: High-perveance W-band Sheet-beam Electron Gun Design

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Abstract: *A design methodology for sheet-beam formation and solenoidal magnetic field transport is described, and a point design for a W-band amplifier gun and beam transport is presented. The gun topology flexibly permits adjustment of beam width to accommodate various interaction circuits while maintaining beam height. This topology has been employed in the design of a 19.5 kV, 3.6 A (1.32 μ-perv.) gun with beam final cross-section of approximately 4.2 mm x 0.32 mm, using the 3-D gun code MICHELLE in conjunction with the magnet code MAXWELL-3D. Beam thermal effects due to cathode temperature are also included in the simulation.*

Keywords: Sheet beam; W-band; electron gun; high perveance; amplifiers.

Introduction

Sheet-beam amplifiers offer the potential of much higher power than is feasible with round (pencil) beam amplifiers of comparable current density. Also, a solenoidal permanent magnet configuration can produce substantially stronger beam focusing than periodic permanent magnets (over suitably short distances), and hence allows much higher current density at a particular beam voltage. However, beam formation and transport are key challenges that must be overcome to fully realize these potential benefits.

For sheet beams, the difficulty is due to the interplay between the electric field (beam space charge and accelerating field) and the applied axial magnetic field, which gives rise to E x B drift. This drift is the root cause of beam edge curling and diocotron effects [1], which distort the sheet beam. Since this drift is proportional to the electric field and inversely proportional to the applied axial magnetic field, its impact is most pronounced in the accelerating region of the gun, where the space-charge and applied electric fields are high and the applied magnetic field is low, in general. Once initiated, this drift will be further exacerbated in the beam transport section due to beam non-uniformity, which is particularly serious for high current and low-voltage sheet beams, as in the case at hand.

To minimize beam distortions, we employ in our design a modular approach, in which the gun region is magnetically shielded to electrostatically form the electron beam. The gun is followed by a matching section, which further compresses the beam in the transverse direction and introduces the formed sheet beam into the uniform magnetic field region for beam focus in the circuit.

Beam Formation

Employing this approach, a 19.5-kV, 3.6-A electron gun has been designed with the 3D gun code MICHELLE [2] in conjunction with the magnet code Maxwell 3D [3]. The cathode is a cylindrical cut surface with a rectangular cross-section of approximately 4 mm in width and 9.7 mm in height. The focus electrode and anode are shaped to ensure that beam compression is only in the beam height direction, with minimal beam excursion in the beam width.

This uniform beam compression is illustrated by Figure 1, which shows the beam cross-section near the cathode and inside the beam tunnel. As can be seen, the beam width remains approximately constant, while the beam height is compressed by a factor of ~30. It is worth noting that due to the rectangular cathode cross-section and uniform beam compression in our design methodology, the beam current density is quite uniform across the beam width. This uniformity is advantageous as it maximizes beam-wave interaction in sheet-beam circuits.

An integrated side view of the beam as it is being compressed in the gun region and matched onto a uniform magnetic field of 9 kG is shown in Figure 2.

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The field is generated by a permanent magnet configuration.

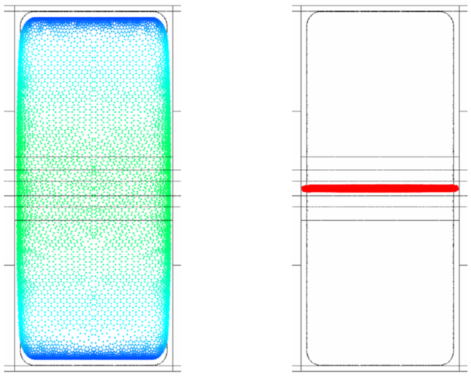

Figure 1: Beam cross-section near cathode (left) and final beam cross-section in beam tunnel (right)

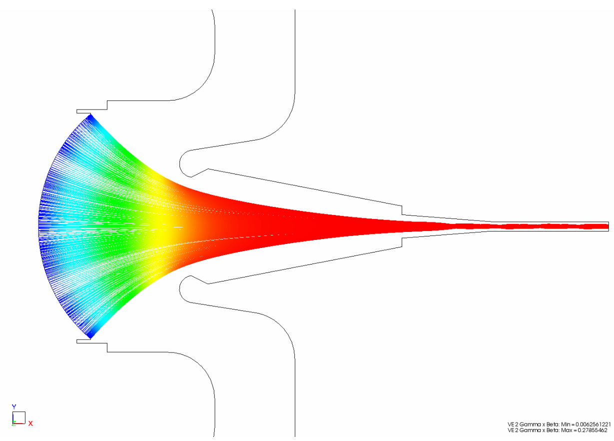

Figure 2: An integrated side view of the electron beam as it being compressed and matched onto a 9-kG uniform magnetic field.

Figure 3 shows a 3-D view of the beam cross-section at fixed axial intervals along the gun for this particular design. Note that the rectangular shape is maintained throughout the beam compression process.

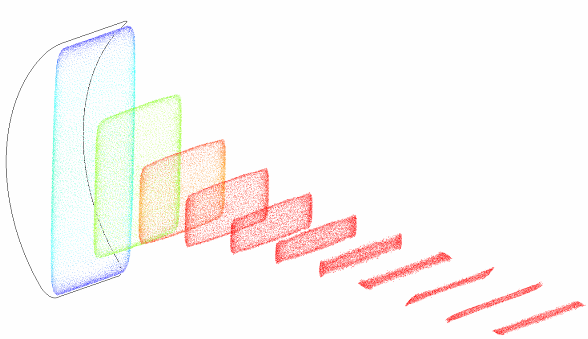

Figure 3: Beam slices at fixed axial intervals.

Transverse beam temperature affects the beam height and must be included in the design. Assuming a cathode temperature of 1200^{o} C, simulation with MICHELLE indicates the final beam height is 320 microns (for comparison purposes, beam height would be 230 microns without thermal effect) at a beam width of 4.2 mm. The final beam size and parameters are suitable for use with our W-band sheet-beam extended-interaction klystron (EIK) topology [4]. It is also important to point out that with our beam forming approach the electron beam width can be adjusted simply by changing the width of the cathode and corresponding focusing electrodes. Thus, gun design can be flexibly modified to provide beam parameters as required by the beam-wave interaction in the circuit.

Beam Transport

Our novel permanent magnet design provides a flat field of 9 kG over approximately 2.0 cm in length (sufficient for our EIK circuit). Simulations with MICHELLE over this length indicate that no beam interception occurs. In fact, the formed beam can be transported in a uniform magnetic field as far as 6 cm with minimal interception. A preliminary collector design is also completed and will be presented.

Conclusion

A design methodology for sheet-beam formation and transport in a uniform (solenoidal) magnetic field is described. A high-perveance, low-voltage sheet-beam gun has been designed based on this methodology. Successfully developed, such a gun can provide the beam source necessary to drive future high power and compact mm-wave amplifiers.

Acknowledgement

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[3] Ansoft Corporation, Pittsburgh, PA.

[4] K. Nguyen, et al. "*Sheet-Beam 90 GHz and 220 GHz Extended-Interaction Klystron Designs,*" IVEC 2007 Conference Abstract Records, p. 193.